RECENT STUDIES IN THE GRENVILLE SERIES OF EASTERN NORTH AMERICA[1]

FRANK D. ADAMS
McGill University, Montreal.

In a paper which has recently appeared[2] a summary of the chief results of a geological study of a large area on the margin of the Laurentian protaxis in eastern Ontario, by Dr. Barlow and the writer, has been presented. The area in question, whose study has just been completed, is one of the largest areas of the protaxis which has hitherto been examined, comprising 4,200 square miles, and the study has furthermore been carried out in much greater detail than in the case of areas formerly examined in Canada, the field work extending over a period of eight years. In a second paper[3] now in press a more detailed account of the great development of nepheline and corundum-bearing syenites found in the area is given.

The area lies near the border of the Laurentian protaxis, north of Lake Ontario and east of Lake Huron, and one of the most conspicuous features of its geology is the great development in it of Logan's Grenville series. It is proposed in the present paper to present certain new facts which have been discovered concerning this series in the area in question, as well as certain general considerations relative to this, which is one of the most extensive and important series of pre-Cambrian Age in North America. A complete description of the area will appear in the form of a report to be issued by the Geological Survey of Canada during the present year.

In *The Geology of Canada*,[4] published in 1863, which contains a statement of the results of the work of the Canadian Survey up to that date, Logan commences the chapter dealing with these rocks as follows:

[1] Communicated by permission of the Director of the Geological Survey of Canada,

[2] Frank D. Adams, "On the Structure and Relations of the Laurentian System in Eastern Canada," *Quarterly Journal of the Geological Society*, May, 1908, p. 127.

[3] "On the Nepheline and Alkali Syenites of Eastern Ontario," *Transactions of the Royal Society of Canada*, 1908.

[4] P. 22.

The rocks which compose the Laurentian Mountains were shown by the Geological Survey in 1846 to consist of a series of metamorphic sedimentary strata underlying the fossiliferous rocks of the Province. They have since been recognized by Sir Roderick Murchison as forming the so-called "Fundamental Gneiss" of the western islands of Scotland and parts of Rosshire and Sutherlandshire, and the name of the Laurentian system as applied in Canada has now been extended to them in Great Britain where, as well as in this country, they are the oldest rocks known and lie at the base of the sedimentary series. They are highly altered to a crystalline condition and are composed of feldspathic rocks interstratified with important masses of limestone and quartzite. The great vertical thicknesses of the series are composed of gneiss containing chiefly orthoclase or potash feldspar, while other great portions are destitute of quartz and composed chiefly of a lime soda feldspar, varying in composition from andesine to anorthite and associated with pyroxene or hypersthene. This rock we shall distinguish by the name of anorthosite.

Logan's exploratory work showed that these ancient rocks underlie enormous areas in Canada. It is now known that they occupy an area of about two million square miles. As their structure is very complicated, he found it impossible to make a detailed study of the whole Canadian shield and therefore decided to select a comparatively limited area in which the Laurentian system had a typical development, and there, by careful mapping, to ascertain its structure and relations. The district which he selected had an area of about fifteen hundred square miles and was situated on the margin of the northern protaxis in the vicinity of the little town of Grenville, some forty miles to the west of the city of Montreal. His map of this area appeared in the atlas which accompained *The Geology of Canada.* This area has come to be known as the "Original Laurentian Area" of Logan, and the succession which he worked out there has found its way into most textbooks.

Since that time other members of the staff of the Geological Survey of Canada, notably Vennor and Ells, have extended our knowledge of this portion of the Laurentian area by mapping large tracts along the margin of the protaxis to the west of the Original Laurentian Area as far as the western border of the Province of Quebec, and thence over into eastern Ontario. In 1897[1] the writer published the results

[1] "Report on the Geology of a Portion of the Laurentian Area lying to the North of the Island of Montreal," with appendices and map, *Annual Report of the Geological Survey of Canada*, Vol. VIII, p. 184.

of a study of a large area lying to the east of the Original Laurentian Area and extending as far as the St. Maurice River, which flows into the St. Lawrence about half-way between Quebec and Montreal. Our knowledge of the Laurentian has also been very considerably extended by the researches of Kemp, Cushing, and others in the Adirondack Mountains, as well as by the extended explorations of Low and others in the far north and by the work of Lawson in the west.

SIR WILLIAM LOGAN'S WORK IN THE LAURENTIAN OF CANADA

Before considering the results of these recent studies it will be of interest to look very briefly at the work done by Logan in the Original Laurentian Area.

This master of stratigraphy found that the Laurentian system, instead of presenting a chaotic mass of crystalline rocks from which no order could be evolved, constituted as a matter of fact a great series of rocks largely stratiform, if not stratified, in character, and which almost everywhere exhibited a foliated structure. Among these rocks he found great bodies of limestone, the importance and significance of which he at once recognized. This limestone was, it is true, frequently very impure and always coarsely crystalline, constituting in fact a true marble. Its chemical composition, however, led him to conclude that it was of sedimentary origin. The limestone occurred in the form of belts or bands, and, being easily recognized in the field, was used by him as a basis for working out the complicated stratigraphy of the district. Being soft and easily disintegrated, it frequently occupies low drift-covered ground, and over considerable tracts of country he was obliged to determine its existence beneath the drift by driving down a sharply pointed iron rod and testing the powder brought up by the rod, by means of acid. He was enabled by the use of this geological cheese-taster to determine the existence of the limestone beneath the drift in many places where its occurrence could not be otherwise ascertained.

Associated with the limestones he found in places bands of quartzite. Bands of hornblendic rocks, now termed amphibolites, often of great thickness, also formed part of the series. He ascertained, however, that orthoclase gneiss was the most abundant rock in the Laurentian. This, he states, varies greatly in character, being

sometimes almost massive and granitic, while elsewhere it is well foliated. It sometimes occurs in great bodies free from all admixture of other rocks, while at other times it is found intimately associated or interbanded with the limestones or other rocks making up the series.

The highly contorted character of this series of rocks made it very difficult to determine its thickness, but Logan regarded the following ascending section as representing approximately the succession and thickness of the various elements constituting the Laurentian in the original area examined by him.

		FEET
1.	Anorthosite, above the Morin band of limestone, the thickness is wholly conjectural	10,000
2.	Orthoclase gneiss, passing gradually into anorthosite, probably includes the quartzite of Quartz Mountain, the anorthosite above it and the gneiss of passage	3,400
3.	Proctor's Lake limestone	20
4.	Orthoclase gneiss	1,580
5.	Crystalline limestone of Grenville, in some parts interstratified with a band of gneiss about	750
6.	Orthoclase gneiss, with several bands of garnetiferous gneiss and quartzite, and with much coarse-grained porphyroid gneiss	3,500
7.	Crystalline limestone of Great Beaver Lake and Green Lake, including two bands of interstratified garnetiferous rock and hornblendic orthoclase gneiss	2,500
8.	Orthoclase gneiss	4,000
9.	Crystalline limestone of Trembling Lake	1,500
10.	Orthoclase gneiss composing Trembling Mountain, lower limit not ascertained, thickness probably exceeds	5,000
		32,250

The base of the series was thus a great body of orthoclase gneiss —the Trembling Mountain gneiss—above which were four belts of limestone, certain of them of great thickness, alternating with orthoclase gneiss; the whole succeeded by a great development of anorthosite.

The alternation of limestone with gneiss was considered by Logan as proving that the whole series represented a great body of highly altered sediments, the oldest sediments recognizable in the earth's history. The foliation exhibited by the bodies of orthoclase gneiss

lying between and below the limestones, as well as that exhibited by the anorthosite, was regarded as the survival of an almost obliterated bedding, and this foliation, as has been mentioned, extended down to the very base of the whole series. The existence of this great thickness of anorthosite superimposed upon, and, therefore, presumably younger than the orthoclase gneiss, was in a brilliant paper by Sterry Hunt, explained as due to a succession of chemical reactions which must necessarily have been developed during the cooling of the earth from whose primeval ocean the whole series was supposed to have been deposited in the order of their succession.[1]

Since Logan's time, however, the great advance in our knowledge of petrography has thrown a flood of light upon the nature of the crystalline schists and a study of the area lying immediately to the east of that mapped by Logan made it evident that Logan's conclusions must be in part revised.

The Fundamental Gneiss, in the first place, is found to be a great body of uniform, fine-grained, foliated granite, showing under the microscope excellent protoclastic structure. It is clearly an igneous intrusion in which foliation has been developed by movement under pressure. The suggestion of stratification which it presents owing to its foliation, is enhanced by the presence in it of occasional lenticular bands of dark amphibolite. These, of course, lie parallel to the foliation, that is, to the direction of movement in the rock, but are evidently inclusions of the overlying rock which was intruded by the granite. The thickness of this fundamental gneiss (5,000 feet), considered even by Logan to be wholly conjectural, must therefore be deducted from the total thickness given in the above section.

The anorthosite, when traced to the east, is also proved beyond doubt to consist of a great body of igneous rock having a pronounced foliation, especially near its margin, and which cuts off the limestone bands where it meets them. Its thickness (10,000 feet), which was also considered by Logan to be wholly conjectural, must also be deducted.

It is furthermore certain, as the result of recent work, that the gneisses associated with the limestones are in part of igneous origin

[1] "The Chemistry of Metamorphic Rocks," *Chemical Geological Essays*, Boston, 1875.

and in part represent highly altered sediments. It is impossible in all cases to distinguish these two classes of rocks, but the distinction can in many cases be made with certainty.

The sedimentary gneisses (paragneiss) are fine in grain and usually occur intimately associated or interstratified with the limestones and quartzites, and very frequently weather to a rusty color. From the thickness of the limestone bands given above, there must be deducted that of the igneous gneiss included in or associated with them.

It is also by no means certain that the four limestones mapped by Logan are all separate bands, seeing that the intervening belts of gneiss, being largely igneous in origin, can no longer be regarded as representing separate stratigraphical elements, but may be intrusions separating portions of one and the same body of limestone. Whether or not this latter presumption represents the truth, can, however, only be determined by a complete re-examination of Logan's work in this area. In the meantime it is certain that the highest and lowest members of his series are bodies of intrusive rock in which a foliation has been induced by pressure. The deduction of these reduces the thickness of the series by 15,000 feet, and that a much greater reduction than this must be made if the true thickness of the sedimentary portion of the series is to be ascertained, is evident from what has been already stated.

In his map of this area, Logan separated the anorthosite and designated it as Upper Laurentian, while the other rocks of the series were classed as Lower Laurentian or Grenville series. In after years the lowest gneiss came to be known as the Fundamental Gneiss or Ottawa Gneiss, while the name "Grenville series" was restricted to the limestone-bearing portion of Logan's Laurentiau.

This work of Logan, while in many respects imperfect, was nevertheless a first approximation to a true knowledge of the Laurentian and served as an excellent basis for the work of subsequent investigators.

Logan subsequently found in eastern Ontario a series of rocks which he considered in all probability to represent the Grenville series in a less altered form, and to these he gave the name of the "Hastings series."

THE HALIBURTON-BANCROFT AREA IN EASTERN ONTARIO

The Haliburton-Bancroft area in eastern Ontario, the mapping of which has just been completed, occupies a position on the margin of the protaxis corresponding to that of the "Original Laurentian Area" but is some 175 miles further west. It is very similar in petrographical character to Logan's area but presents a somewhat greater variety of rock types, the distribution of twenty different rock types being represented on the Bancroft sheet accompanying the report on the area in question.

The Grenville series in this area presents a diversified series of undoubted stratified rocks among which limestones preponderate, but they rest upon and are invaded by an enormous body of gneissic granite.

To the southeast, toward the margin of the Paleozoic cover, the sedimentary series is largely developed and is comparatively free from igneous intrusions. Toward the northwest, however, the granite, in ever increasing amount, arches up the sedimentary series and wells up through it, in places disintegrating it into a breccia composed of shreds and patches of the invaded rock scattered through the invading granite, until eventually connected areas of the sedimentary series disappear entirely and over hundreds of square miles the granite and granite gneiss alone are seen, holding, however, in almost every exposure, inclusions which represent the last scattered remnants of the invaded rocks.

The type of structure presented by the invading granite is that of a bathylith.

The limestones.—The limestones in this Laurentian district are very thick and underlie a large part of the area. In their more altered form they exactly resemble those described by Logan in the areas examined by him, but to the southeast of the Bancroft sheet, where the invading granite is less abundant and the alteration of the invaded strata is correspondingly less pronounced, the limestones appear in less-altered forms and eventually pass into fine-grained, grayish-blue varieties in which the bedding is perfectly preserved and concerning whose truly sedimentary character there can be absolutely no doubt. The gradual transition of the comparatively unaltered bluish limestone into the coarsely crystalline white marble takes place by the develop-

ment in the former of little strings or irregular patches of coarsely crystalline white calcite, usually following the bedding planes. These become larger and more numerous on going north in the area toward the granite intrusions, until eventually the whole are transformed into great bodies of white marble. Here and there through this marble, where it is very thick, small remnants of the original blue limestone can occasionally be found.

Enormous bodies of nearly pure limestone or marble occur in many parts of the area, but elsewhere it becomes impure, owing to the presence of numerous scales and granules of various silicates distributed through it, or owing to the appearance of numerous little bands of silicates representing impurities in the original limestones, which, under the influence of metamorphism, develop into gneisses and amphibolites of various kinds. Where these little gneiss or amphibolite bands become increasingly abundant, the limestone passes over into paragneiss or into some one of the varieties of amphibolite.

The limestone in what may be called its usual development, that is, in its highly crystalline form, is a white, cream-colored, or pinkish marble, and is generally very coarse in grain. The little grains or scales of foreign minerals scattered through it are usually arranged so as to indicate the lines of the original bedding. No less than thirty-seven species of these minerals have been found in the limestones in this area, of which phlogopite, malacolite, serpentine, scapolite, graphite, and pyrite are the most common.

That the limestone has in many places been subjected to great movements can be distinctly seen on the face of any high cliffs or where other large surfaces of the limestone are exposed. Here the interstratified bands of gneiss or amphibolite can be seen winding to and fro over the exposed surface, often folded back upon themselves or broken into fragments which have become widely separated from one another by the movements, the more plastic limestone having flowed in between them, the rock often in this way taking on the appearance of a coarse conglomerate.

The quartzites.—Quartzite is not common in this area. Where it occurs it is found interstratified with the crystalline limestones and rusty weathering paragneisses. It is well foliated and rather fine

in grain, sometimes containing a certain amount of feldspar as an accessory constituent, and elsewhere containing some pale-green pyroxene, which is evidently derived from the alteration of a certain amount of calcareous matter originally present.

Under the microscope the quartz of these quartzites is seen to have the form of elongated grains arranged in the direction of the foliation and showing very marked strain shadows, sometimes passing into a distinct cataclastic structure. There is every reason to believe that these quartzites represent, in most cases at least, altered sandy sediments.

The gneisses of sedimentary origin (*paragneiss*).—These gneisses differ distinctly in appearance from the foliated granite gneisses already referred to, and which constitute the bathylithic intrusions. They are fine in grain and show no protoclastic or cataclastic structure, the original material having been completely recrystallized. They have an allotriomorphic structure, with a tendency of certain of the constituent minerals to elongate themselves in the direction of the original bedding. While quartz, feldspar, and biotite are among the constituents present, the mica is usually more abundant than in the granite gneisses, and, in addition, garnet, sillimanite, graphite, and pyrite are very frequently present, the last giving rise to a prevailingly rusty color on the weathered surface. These gneisses occur in the form of well-defined beds and are usually found intimately associated with the limestones. They resemble in many respects the hornstones which are found in granite contact zones, but are rather more coarsely crystalline than is usual in this class of rocks.

These gneisses, while presenting a general similarity in appearance, show a considerable diversity in composition and are evidently derived from the recrystallization of sediments which varied considerably in character. The two following analyses show extreme cases of this variation.

No. I occurs interstratified with beds of white garnetiferous quartzite at St. Jean de Matha in the Laurentian district to the north of Montreal. It is composed of quartz, orthoclase, garnet (in large amount), and sillimanite, with smaller amounts of rutile, biotite, pyrite, graphite, and serpentine, the latter mineral resulting from the

alteration of some constituent which has now entirely disappeared. As will be seen, the rock has the composition of an ordinary clay slate, possessing the characteristic high content of alumina with a low percentage of alkalis and a great preponderance of magnesia over lime, which is characteristic of these rocks.[1]

	No. I	No. II
SiO_2	61.96	79.70
TiO_2	1.66	.30
Al_2O_3	19.73	8.29
Fe_2O_3		.41
FeO	4.60	1.17
FeS_2	4.33	Not det.
MnO	Trace	.03
CaO	.35	.67
BaO		.08
MgO	1.81	.76
Na_2O	.79	1.43
K_2O	2.50	4.11
P_2O_5		.04
Graphite	Not det.	3.00
Water	1.82	.70
	99.55	100.69

No. II is from the township of Stanhope in the Haliburton area and is distinctly different in composition. If the "Mode" or percentage mineral composition of this rock be calculated, it is found to be as follows:

	PER CENT.
Quartz	55.20
Orthoclase	18.94
Oligoclase	14.46
Biotite	3.45
Muscovite	3.50
Rutile	.30
Apatite	.09
Calcite	.28
Graphite	3.00
Water	.54
	99.76

[1] See F. D. Adams. "A Further Contribution to our Knowledge of the Laurentian," *American Journal of Science*, July, 1895.

If the quantitative classification be adopted, this rock would find its place as a Tehamose, a division which includes many granites and liparites, and, so far as its chemical composition is concerned, might be of igneous origin, although few liparites contain so high a percentage of silica. Its mode of occurrence and structure, however, indicate that it is of sedimentary origin and it evidently results from the recrystallization of some arkose-like material derived from the disintegration of granite rocks.

These sedimentary gneisses (paragneisses) clearly represent deposits of argillaceous, or in some cases arenaceous sediment, often more or less calcareous, which were laid down in the same sea in which the limestones were accumulated.

In a extreme southern portion of the Bancroft area there is a considerable development of clay stones (often siliceous or calcareous) which probably represent these gneisses in a less altered form, but which probably, at the same time, hold a considerable admixture of volcanic material.

The amphibolites.—Intimately associated with these sedimentary gneisses and the limestones on one hand, and with the gabbros and diorites on the other, are other rocks which are grouped under the name of amphibolite. While many varieties of these rocks occur in the area, differing considerably from one another in appearance, they have as common characteristics a dark color and a basic composition. Quartz, which is one of the commonest constituents in the gneisses, is absent, or is present only in very small amount, while hornblende and feldspar, the latter chiefly plagioclase, are the chief constituents of the rock. Pyroxene or biotite often replaces the hornblende in part. In places the sedimentary gneisses fade away into occurrence of amphibolite when traced along the strike. Masses of amphibolite also, as has been mentioned, abound as inclusions throughout the granite of the bathyliths.

These amphibolites, furthermore, are not peculiar to this area but occur abundantly everywhere in the Laurentian. They have always proved to be one of the chief difficulties in the way of a correct understanding of the geology of this system, seeing that it has been impossible to do more than indulge in conjectures concerning their origin. The same difficulty has been met with in the case of these and allied

rocks occurring elsewhere, as for instance the trap granulites of the Saxon Granulitgebirge or the amphibolites of the crystalline complex of certain portions of the Alps, whose origin remains in doubt while that of the rocks with which they are associated has been definitely determined.

As the result of a very careful examination, it has been possible to prove conclusively that in this area the amphibolites have originated in three entirely different ways, the resulting rocks, although of such diverse origin, often being identical in appearance and composition. This remarkable convergence of type, whereby rocks of widely different origin come to assume identity of character, explains the difficulty which has been experienced up to the present time in arriving at a satisfactory conclusion concerning their genetic relations. These three ways are: (*a*) By the metamorphism and recrystallization of impure calcareous sediments; (*b*) By the alteration of basic dykes and similar igneous intrusions; and (*c*) By the contact action of the granite bathyliths on the limestones through which they cut. The question of the origin of these amphibolites is discussed elsewhere.[1]

THICKNESS OF THE GRENVILLE SERIES IN THE HALIBURTON-BANCROFT AREA

While in most parts of this area the Grenville series is so torn to pieces by igneous intrusions that no development of it can be found sufficiently continuous to enable its thickness to be measured, there are in certain parts of the area developments where these intrusions are distinctly subordinate and in which such measurements can be made with at least the same degree of accuracy as in the case of any other pre-Cambrian series.

One such district is that where the four townships of Anstruther, Burleigh, Chandos, and Methuen meet. Here a well-defined synclinal is succeeded to the east by an anticlinal, and the following succession of strata, which however does not represent a complete section through the Grenville series of this area, is expressed in descending order (Burleigh-Chandos section).

[1] *Journal of Geology*, Vol. XVII, No. 1.

	FEET
Limestone of Jack's Lake	6,770
Rusty weathering gneiss with associated amphibolites, crossing Lots 29–35 of Range I of Anstruther	5,754
Limestone with bands of sedimentary ("feather") amphibolite north of Loon Lake	3,060
Amphibolite north of Loon Lake	2,190
Limestone at Duck Lake (nearly flat, only surface exposed), say	50
	17,824

Another line of section along which the Grenville series is excellently exposed and along which measurements with a view to determining the thickness of the series may be made, is furnished by the Hastings road. This is one of the most striking sections of strata of pre-Cambrian Age to be found anywhere in the world. The road was constructed many years ago by the government for the purpose of enabling settlers to penetrate into what was then a very wild, remote, and inaccessible portion of the Dominion. A line was drawn on a map and orders were given to lay out the road along the line in question. The result was that a long road was constructed, starting from the rear line of the township of Madoc, running in an almost straight line to the Madawaska River, holding throughout almost its entire course a direction of N. 20° W. This road, which traverses the whole width of the Bancroft sheet and almost the whole width of the area embraced by the Haliburton sheet, fortunately for students of geology, runs about at right angles to the strike of the country rock, and throughout the whole southern portion of its course traverses the Grenville series, affording excellent exposures. The selection of this course for the road was, however, correspondingly unfortunate for the settlers who took up land in the district, since the road holds its course quite irrespective of hill or valley, and in its course passes directly across several great gabbro intrusions which give rise to an exceedingly rough type of country, and which might easily have been avoided had a slightly different line been adopted.

As will be seen by consulting the Bancroft sheet of the Ontario series of maps now being issued by the Geological Survey of Canada, throughout a distance of 25.3 miles from lot 30 of the township of Madoc to 60 in the township of Faraday, except where it crosses the gabbro intrusions above mentioned, whose width has been

deducted in arriving at the measurement just given, the Hastings road passes continuously across the limestone and amphibolites of the Grenville series, and throughout this whole distance crosses these latter practically at right angles to their strike.

Furthermore, throughout the whole distance these strata dip in a southerly direction at high angles. Here and there, at long intervals and for a few yards, a reversed or northerly dip can be observed, but this is merely local owing to a minor undulation in the strata which has no stratigraphical significance.

The angle of dip naturally varies somewhat from place to place, but the average dip may be taken as 45°. This is a minimum estimate, the average dip along the whole section being in all probability somewhat higher. Taking this value we obtain the following result:

Apparent thickness of the Grenville series along the line of section
=25.3 miles=133,584 feet.
True thickness of the Grenville series along this line of section
=17.88 miles=94,406 feet.

It must be noted that the series is one which along the whole length of this section presents a continuous alternation of beds of varying character, so that it is not a foliation but a true bedding that is observed and measured.

It is, moreover, to be noted that while this thickness is so great as to suggest reduplication of some sort by isoclinal folding or by faulting, there is no stratigraphical evidence that such reduplication exists, and a fact of very great importance to be noted is that if there be such reduplication, the basement upon which the series was deposited is nowhere brought up along the whole line of section as would undoubtedly be the case unless the series reduplicated by folding was of enormous thickness.

For purposes of comparison the estimated thicknesses of some of the other great developments of pre-Cambrian rocks in North America are presented on a later page.

In all these districts there is, as in that at present under consideration, a possible error due to partial repetition by folding.

In the Grenville series, as has been stated, limestones predominate,

and these sections afford data for determining the relative proportion of limestone present.

In the Burleigh-Chandos section given above the Jack Lake limestone is essentially a body of pure limestone, while the Loon Lake limestone band may be estimated to be about half limestone. This gives a thickness of about 8,350 feet of limestone in that section out of a total of 17,824 feet, that is to say, 46.8 per cent. of pure limestone.

The estimated thicknesses above referred to are as follows:

	FEET
Huronian-Marquette Iron Range, Michigan, U. S. A.[1]	12,590
Huronian-Menominee Iron Range, Michigan, U. S. A.[2]	4,650 to 6,400
Huronian-Penokee Iron Range, Michigan, U. S. A.[3]	13,950
Huronian-Mesabi Iron Range, Minnesota, U. S. A.[4]	6,800 to 8,800
Huronian & Keewatin-Vermilion Iron Range, Minnesota, U. S. A.[5]	13,350 to 15,550
Couchiching series in Rainy Lake District, Ontario, Canada[6]	23,760 to 28,754

With these may be compared:

Belt Formation in Montana, U. S. A.[7]	12,000
Pre-Cambrian of Lewis & Livingstone Ranges, Montana, U. S. A.[8]	9,900 to 10,700

[1] C. R. Van Hise, and W. S. Bayley, "The Marquette Iron-bearing District of Michigan" (Monograph), *U. S. Geol. Survey*, 1897.

[2] W. S. Bayley, "The Menominee Iron-bearing District of Michigan" (Monograph), *U. S. Geol. Survey*, 1904.

[3] R. S. Irving and C. R. Van Hise, "The Penokee Iron-bearing Series of Northern Wisconsin and Michigan" (Monograph), *U. S. Geol. Survey*, 1892. This thickness is arrived at by adding to the aggregate thickness of 1,950 ft., given for cherty limestone, quartz slate, and iron-bearing member an additional thickness of 12,000 ft. for the upper slate member, which thickness is that of the Hanbury slate, which in the Menominee Range is its equivalent.

[4] C. K. Leith, "The Mesabi Iron-bearing District of Minnesota" (Monograph), *U. S. Geol. Survey*, 1903.

[5] J. M. Clements, "The Vermilion Iron-bearing District of Minnesota" (Monograph), *U. S. Geol. Survey*, 1903.

[6] A. C. Lawson, "Annual Report of Progress," *Geol. Survey of Canada*, 1885, p. 108 c. c.

[7] "Pre-Cambrian Fossiliferous Formations," *Bull. Geol. Soc. Am.*, Vol. X, pp. 201–15.

[8] Bailey Willis, "Stratigraphy and Structure of Lewis and Livingstone Ranges, Montana," *Bull. Geol. Soc. Am.*, Vol. XIII, pp. 316–24.

In the section along the line of the Hastings road, it is estimated that the "blue limestone" and the "limestone and amphibolite," which represent the calcareous part of the series, contain about two-thirds of their thickness of pure limestone. This would give a thickness of 50,286 feet of pure limestone out of a total thickness of 94,406 feet, equal to 53.3 per cent. This latter section, being a much longer one, probably represents more nearly the average proportion of limestone in the Grenville series as developed in this area, which in its turn affords a representative area of the series as it occurs in Canada, so that it may be stated that the Grenville series, as a whole, contains rather more than one-half its thickness of pure limestone. The thickest development of limestone in any occurrence of the Huronian in America is the Randville dolomite in the Menominee Range, which attains a thickness of 1,500 feet. In the Belt Formation and in the series of pre-Cambrian rocks in the Lewis and Livingstone Ranges, there is a thickness of limestone amounting to 4,400 and 5,400 feet respectively.

As will be seen, the thickness of limestone in the Grenville series is much greater than in any of these.

It may be safely stated that the Grenville series presents by far the thickest development of pre-Cambrian limestones in North America, and that it presents at the same time one of the thickest, if not the thickest, series of pre-Cambrian rocks on this continent.

AREAL EXTENT OF THE GRENVILLE SERIES

Not only has the Grenville series a great thickness, but it has a very wide areal distribution. It is exposed along the southern border of the protaxis from the Georgian Bay eastward to a point considerably beyond the St. Maurice River, which flows into the St. Lawrence at the town of Three Rivers. It extends to the northward in the Laurentian Highlands at least as far as the latitude of Cobalt, although not reaching so far west as this point, which lies in a Keewatin and Huronian district. To the southeast it is stated by Professor H. P. Cushing to be exposed at intervals over the whole Adirondack area, while to the southwest deep borings under the city of Toronto have brought up, from beneath the Paleozoic, cores of a white crystalline limestone which evidently belongs to the same series. The area thus

outlined embraces 83,000 square miles. In areal extent, therefore, it can be compared only with certain of the greatest developments of the Paleozoic limestones in North America as for instance the Knox Dolomite of the Southern Appalachians. Over this area of 83,000 square miles, the Grenville series is not, of course, now continuously exposed. It is penetrated in many places by great intrusions of granite and anorthosite. This is especially true of the Adirondack Mountains in which these intrusives are especially numerous. This area, however, is one which was originally undoubtedly covered by a continuous development of the Grenville series.

In all probability, however, the areal distribution of the Grenville series is much greater than this. In many parts of the Laurentian Highlands far to the north of the limit here taken as the boundary of the Grenville series, areas of white crystalline limestone and associated rocks are found which are identical in character with that of this series. Enormous developments of such limestones, identical in all respects with the Grenville series, are, for instance, found about the shores of Hudson Straits. Whether these northern limestones belong to the same series is however not at present known with certainty. Definite information on this point may be obtained as our knowledge of this great northern country becomes more complete. It is furthermore very highly probable, as the Grenville series along the southern margin of the protaxis everywhere disappears to the south beneath the Paleozoic cover, that in this direction it originally had a very much greater extent than that over which it is at present exposed. In this connection it is important to note that the pre-Cambrian limestone series of the Highlands of New Jersey, which has recently been studied by Bayley, has by him been correlated with the Grenville series.[1] The facts, however, in our possession at present show that the Grenville series is one of the greatest limestone series in North America and that it presents, as has been mentioned, the greatest development of limestone known in the pre-Cambrian.

CORRELATION OF THE GRENVILLE SERIES

In connection with the Grenville series one other question presents itself, namely, whether this great series represents a continuous suc-

[1] "Preliminary Account of the Geology of the Highlands of New Jersey," *Science*, May 8, 1908, p. 722.

cession of strata or whether in it there may be two series of identical petrographical character, intimately associated, and which have been subjected to the same intense and widespread metamorphism. The information hitherto accumulated and bearing on the question may be briefly stated. In the report upon the Haliburton-Bancroft area, by Dr. Barlow and the writer, to which reference has already been made, the occurrence of conglomerates at a few separated points in the southern portion of the area is described and the conclusion is reached that certain of these are probably of epiclastic origin and indicate an unconformity in the series. If two series be present, however, the intense metamorphism and folding has rendered it impossible to delimit them in the area embraced by the report in question. When the international committee representing the geological surveys of the United States and Canada (appointed for the purpose of effecting a correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "Original Laurentian Area" and Eastern Ontario) visited the Madoc district, which lies to the south of the Haliburton-Bancroft area, they examined a conglomerate near the town of Madoc and concluded that it probably represented a break in the pre-Cambrian sedimentary limestone series as there developed. Miller and Knight, who visited the district in the autumn of last year, stated in a short paper which appeared in the *Report of the Ontario Bureau of Mines* for 1907 (p. 202), and which was afterward read before the American Geological Society, that "a few days in the field has made the relationship of the sedimentary series quite plain, and the view that the Grenville and Hastings series constitute one series, the former being a more highly altered phase of the latter, is no longer tenable." A careful study extending over many months, however, shows that Logan was quite right and that the comparatively unaltered strata of what he mapped as the Hastings series pass over imperceptibly into the typical Grenville series. What the committee saw, and Messrs. Miller and Knight have substantiated, is that within this unaltered "Hastings series" of Logan, as also probably in the more altered "Grenville" phase of the same rocks, there are two series which are petrographically identical. These series, when worked out, should be distinguished by specific names, as Upper and Lower Grenville, or one may be termed the "Madoc series." Logan's "Hast-

ings series" is the less altered phase of both and to employ it now, to designate either, is to use it in a new sense differing from that of Logan and thereby introduce confusion in the nomenclature. Messrs. Miller and Knight conjecturally set down the lower of these two series, with its enormous body of limestone and other sediments, as Keewatin and as the equivalent to the Keewatin iron formation of Lake Superior, correlating the upper series with the Huronian.

Van Hise in his recent "Presidential Address,"[1] however, very properly declines to accept this view until some evidence has been adduced in favor of such a supposition.

In fact, if conjecture must be indulged in, it is much more reasonable to correlate the whole series, being, as it is, essentially a great sedimentary limestone series, with the Huronian, owing to the fact that as we come east in the Huronian developments of the iron ranges of Lake Superior, limestones become more abundant. The thickest and greatest bodies of limestone in the whole western pre-Cambrian are those of the Menominee Range. It may easily be that still further east the Huronian becomes still more highly calcareous and takes on essentially a limestone facies, while the Keewatin has essentially a pyroclastic development.

But it must be borne in mind that so far as is known at present, the Grenville series may be a distinct entity, separate from either and differing in age from both. This can only be ascertained by a further detailed examination of the intervening areas.

Whatever may be the result of future studies—whether it be established that the Grenville series is to be correlated with members of the pre-Cambrian development in the west or whether it proves to be a series differing in age from any of these—it remains the greatest development of limestone known in the pre-Cambrian of North America and one of the greatest limestone developments of any age.

[1] *Bull. Geol. Soc. of America*, March 30, 1908.